Efficient Backoff Algorithm in Wireless Multihop Ad Hoc Networks

[1]Chien-Min Wu, [2]Hui-Kai Su, [3]Wang-Hasi Yang
*[1],Corresponding Author *Nanhua University, cmwu@mail.nhu.edu.tw*
[2]National Formosa University, hksu@nfu.edu.tw
[3]Hsiuping Institute of Technology, yangwh@mail.hit.edu.tw
doi:10.4156/ijact.vol3. issue1.10

Abstract

The IEEE 802.11 standard, currently used in wireless multihop ad hoc networks, wastes bandwidth capacity and energy resources because of many collisions. Previous studies have shown that controlling the contention window size at a given node can decrease its probability of collisions. In this paper, we propose an efficient backoff scheme and evaluate its performance in ad hoc networks. Our backoff mechanism that we devised grants node access to the channel, based on its probability of collision for a transmitted frame in comparison with those nodes in the two-hop contention area. In addition, the new stage minimum contention window size is the previous stage maximum contention window size. We use simulation experiments to evaluate the effective performance of our scheme in an ad hoc network. Our extensive ns-2-based simulation results have shown that the proposed scheme provides excellent performance in terms of bandwidth, energy awareness, end-to-end goodput, as well as packet delivery ratio.

Keywords*: Ad Hoc Networks, Backoff, Ns-2*

1. Introduction

There has been a growing interest in mobile wireless networks in recent years. Such networks are formed by mobile hosts (or nodes, users) that do not have direct links to all other hosts. They can be rapidly deployed without any established infrastructure or centralized administration; in this situation, they are called ad hoc networks [1]. Because of the greater affordability of commercial radios, ad hoc networks are likely to play an important role in computer communications. The applications of ad hoc network are in building, campus, battlefield or rescue environments.

Unlike wired networks, problems such as: mobility of nodes, shared broadcast channel, hidden and exposed terminal problem, and constraints on resources, such as bandwidth and battery power, limit the applications of ad hoc networks. Due to the above mentioned factors, providing energy aware, packet delivery ratio, and end-to-end goodput guarantees in ad hoc networks are some tough propositions.

Packet scheduling in the Medium Access Control (MAC) layer is for choosing the next packet to transmit, such that a real attempt is made to satisfy the end-to-end delay and packet delivery ratio guarantees. Wireless scheduling algorithms significantly differ from their corresponding wired network. In a wired network, when a node has data packets for transmission, it cares only for the packets in its own transmission queue. But in ad hoc networks, the channel is broadcast; multiple nodes may contend for the channel simultaneously, resulting in collisions. To avoid the collision problem, a node must be aware of traffic at nodes in its two-hop contention area [2]. Therefore, an efficient contention window control algorithm is an important issue for packet scheduling in ad hoc networks.

Recently, the renewed interests in ad hoc networks have centered on using the IEEE 802.11 MAC mechanism. In [3], the authors raised the question: Can the IEEE 802.11 work well in wireless ad hoc networks? They concluded that the protocol was not designed for multihop networks. Although IEEE 802.11 MAC can support some ad hoc network architecture, it is not intended to support the wireless multihop mobile ad hoc networks, in which connectivity is one of the most prominent features. The performance of IEEE 802.11 MAC mechanism is determined by contention window control scheme, RTS/CTS mechanism, transmission range, etc. In addition, whether or not the IEEE 802.11 MAC protocol is efficient will affect the performance of ad hoc networks. The metrics for the performance of 802.11 ad hoc networks may have throughput, delay, jitter, energy dissipation, etc.

A simulation analysis of the contention window control mechanism in the IEEE 802.11 standard has been presented in [4]. Since the backoff and contention window are closely related, the selection of the contention window will affect the network throughput. The authors in [4] showed the effective throughput and the mean packet delay versus offered load for different values of the contention window parameter and the number of contending stations. The throughput and the mean frame delay, as functions of offered load for different RTS threshold values and numbers of stations transmitting frames of random sizes, are presented in [5]. When the number of stations increases, the RTS threshold should be decrease. While transmitting frames of random sizes, it is recommended to always set the RTS/CTS mechanism independent of the number of contending stations. The absence of a RTS/CTS mechanism entails considerable network performance degradation, especially for large values of offered load and numbers of contending stations.

The influence of packet size on the network throughput has been discussed in [6]. When the load is fixed and the packet size is increased, the contending numbers will be decreased and the network performance will be degraded. If the hidden terminal problem occurs, the performance worsens. When the network load is not heavy, the network performance varies slightly as the packet size changes. When the network load is heavy, the hidden terminal problem worsens and the network performance is lowered for the longer packet size.

Under a wide set of network and load conditions, multi-hop networks have lower performance than do single hop networks [7]. Data throughput is maximized when all nodes are in range of each other. The performance degradation in networks may be explained by the fact that channel contention in mobile ad hoc networks based on the 802.11 standard is not ideal.

A new backoff algorithm is proposed in [8] and the authors model it with a Markov chain; its saturation throughput is measured under several conditions and several sets of parameters which are to be adjusted according to the network condition, with the aim of approaching maximum throughput when the stations are saturated.

In [9], the author proposed a Markov Chain to model the IEEE 802.11 DCF. This Markov chain model analysis applies to both packet transmission schemes employed by DCF; for the model, the author proposed an extensive throughput performance evaluation of basic and RTS/CTS access mechanisms.

In [10], the author proposed an enhanced distributed channel access (EDCA) mechanism under saturation condition and analyzed the throughput and delay performance of EDCA.

In this paper, we present the results of a simulation study that characterizes the energy dissipation, packet delivery ratio, and throughput of ad hoc networks. In particular, we use the CBR connection numbers as the main varying parameters for the above mentioned performance metrics. If the contention window control scheme does not consider the probability of collision for a transmitted frame of a node, this may cause some nodes having shorter life time than other nodes. And this situation will affect the establishment of a route and degrade the performance of the entire network. In order to increase throughput and save power, if a node has higher probability of collision for a transmitted frame, the node should have smaller backoff time to transmit its packets. On the other hand, if a node has lower probability of collision for a transmitted frame, the node should have larger backoff time. In addition, we decrement the contention window size by just one unit instead of resetting CW to $CW_{\min}$. Therefore, we redefine the contention window control mechanism in IEEE 802.11 DCF as an efficient backoff scheme.

2. IEEE 802.11

IEEE 802.11 is a standard for wireless ad hoc networks and infrastructure LANs [11-14] and is widely used in many testbeds and simulations in wireless ad hoc networks researches. IEEE 802.11 MAC layer has two medium access control methods: the distributed coordination function (DCF) for asynchronous contention-based access, and the point coordination function (PCF) for centralized contention-free access. In this paper, we consider the IEEE 802.11 DCF MAC protocol as the medium access control protocol in wireless ad hoc networks.

The DCF access scheme is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol [15]. Before initiating a transmission, a station senses the channel to determine whether another station is transmitting. If the medium is found to be idle for an interval that exceeds the distributed inter-frame space (DIFS), the station starts its transmission. Otherwise, if the medium is busy, the station continues monitoring the channel until it is found idle for a DIFS. A random backoff interval is then selected and used to initialize the backoff timer. This timer is decreased as long as the channel is sensed as being idle, stopped when a transmission is detected and reactivated when the channel is idle again for more than a DIFS. When a receiver receives a successful data frame then, it then sends an acknowledgement frame (ACK) after a time interval called a short inter-frame space (SIFS) to the sender.

An optional four way hand-shaking technique, known as the request-to-send/clear-to-send (RTS/CTS) mechanism is also defined for the DCF scheme [9]. Before transmitting a packet, a station operating in the RTS/CTS mode "reserves" the channel by sending a special RTS short frame. The destination station acknowledges the receipt of an RTS frame by sending back a CTS frame, after which normal packet transmission and ACK response occur. Since collision may occur only on the RTS frame, and it is detected by the lack of CTS response, the RTS/CTS mechanism allows increased the system performance by reducing the duration of a collision when long messages are transmitted. The RTS/CTS is designed to combat the hidden terminal problem.

Backoff is a well known method for resolving contentions between different stations willing to access the medium. The method requires each station to choose a random number between 0 and a given number, and wait for this number of slots before accessing the medium, while always checking whether a different station accessed the medium before. The integer number of backoff time slots is uniformly drawn in a defined interval called the contention window.

The algorithm used by 802.11 to make this contention window evolve is called Binary Exponential Backoff (BEB). After each successful transmission, the contention window is set to $[0, CW_{\min} - 1]$ (its initial value). When node successive collisions occur, the contention window is set to $[0, \min(1024, 2^i CW_{\min} - 1)]$; *i* is the number of retransmission; if *i* > 7, the contention window is reset to its initial value. It is the retry limit of the BEB algorithm [16].

The following equation is the backoff mechanism for IEEE 802.11.

$$Backoff = INT(CW * Random()) * SlotTime$$

where

CW = an integer between *CWmin* and *CWmax*;
Random() = real number between *0* and *1*;
SlotTime = transmitter turn-on delay + medium propagation delay + medium busy detect response time.

3. Minooei IEEE 802.11(M802.11)

In [8], the authors proposed an M802.11 backoff algorithm and modeled it with a discrete-time Markov chain. The authors suggested choosing *CW* (Contention Window) from the intervals:

$$[CW_{i-1}, CW_i],\ i = 1, 2, \cdots\cdots, m$$
$$[1, CW_0], i = 0$$

Where CW_i is the contention window of the *ith* backoff stage, and with the condition of the distances between the CW_i strictly increasingly. When a frame has collided *i* times, with increasing *i* the contending stations which are at the same stage as the station under consideration, are too many and the range of choosing $CW * Random()$ should become larger; this is accomplished by having the above mentioned condition and by having this lower boundary for $CW * Random()$ in M802.11. In this way the contending stations are also classified according to their backoff stages. The advantage of this method is classification of the stations by just incrementing the range of backoff times for a fixed number of stations.

M802.11 decrements the contention window size by just one unit instead of resetting CW to $CW_{\min}$. M802.11 just reached a contention window stage which is optimal for traffic at that period of time, so it is better not to lose the frame and it seems that in this way delays will also decrease.

The following equation is the contention window control mechanism for M802.11.

$$Backoff = Uniform[(2^{i-1} * CW_{\min} - 1), (2^{i} * CW_{\min} - 1)] \cdot SlotTime$$

4. Efficient backoff mechanism (E802.11)

The objective of the efficient backoff procedure is to save power and increase the throughput for a node with respect to those nodes in the two-hop contention area of the node. Let i denote the number of retransmission attempts made for a packet, and $i_{\max}$ represent the maximum number of retransmission attempts permitted.

$$Backoff = INT((1-p) * CW_{\min} + Uniform[(2^{i-1} * CW_{\min} - 1), (2^{i} * CW_{\min} - 1)]) \cdot SlotTime$$

where p is the node's frame collision probability, and $Uniform[*]$ is the random number generation function with uniform distribution.

If a node had a higher probability of frame collision in its two-hop contention region, then it will have a lower backoff time according to our efficient backoff mechanism; otherwise, it will have higher backoff time.

Table 1. Simulation parameters

Parameter	**Value**
Nominal bit-rate	2 Mb/sec
Nominal radius	250 m
Number of nodes	100
Square area	670 m x 670 m
Simulation time	150 sec
Packet size	512 byte
Data rate	20 packets/sec
UDP header	8 byte
IP header	20 byte
MAC header	24 byte
Physical layer header	28 byte
CBR connections	5, 10, 15, 20, 25, 30
Energy dissipated for transmit	2 joule
Energy dissipated for receive	1 joule
Energy dissipated for sleep	0.01 joule
Transition power	0.05 joule
Initial energy	200 joule
Sleep time	1 sec
Transition time	0.005 sec

5. Simulation Environment

We used simulations to study the performance of the ad hoc network using the IEEE 802.11 DCF MAC. Results reported in this paper are performed under *ns2* network simulator [17]. The radio model has characteristics similar to a commercial radio interface, Lucent's WaveLAN [18]. WaveLAN is a shared-media radio with a nominal bit-rate of 2 Mb/sec and a nominal radius of 250 m. The link layer models the complete distributed coordination function (DCF) MAC protocol of the IEEE 802.11 wireless LAN standard [11].

We placed great effort on studying the impact of a node's probability of frame collision on the network performance. The node's probability of collision for a transmitted frame is added to the efficient backoff mechanism in E802.11. In most simulation runs, we considered 100 nodes randomly distributed over a square area of $670 \times 670m^2$, and simulated 150 sec of real time. To focus on the power awareness study, we did not consider mobility in this paper and all nodes were assumed to be stationary, in order to eliminate packet loss due to broken routes caused by mobility.

Communications between nodes are modeled using a uniform node-to-node communication pattern with constant bit rate (CBR) UDP traffic sources sending data in 512-byte packets at a rate of 20 packets/sec [19]. Each CBR source corresponds to 94,720 bps bandwidth requirement for data frames (including the 8-byte UDP header, 20-byte IP header, 24-byte MAC header and 28-byte physical layer header) at the radio channel and 81,920 bps useful data throughput. A total of 5, 10, 15, 20, 25, 30 CBR connections were generated to represent different levels of loading, with a node being the source of only one connection. All CBR connections were started at times uniformly distributed during the first sec of simulation and then remained active throughout the entire simulation run. Table 1 lists the simulation parameters in this paper.

Each of our simulation results is the average from 5 randomly generated network topologies. Furthermore, in order to generate a more uniform topology so that the network will not become disconnected when N (the average number of neighbors) is small, we divided the topology into 25 regions and 4 nodes were randomly placed in each region. The distances were also uniformly distributed between the source node and the destination node. That is, we made sure that there were roughly equal numbers of short, medium and long connections.

In wireless networks, a routing mechanism is needed for the communications between two hosts that are not within wireless transmission range of each other. We chose DSR (Efficient Source Routing), a commonly used source routing protocol in the wireless multihop ad hoc networks [20], as the routing protocol in our simulations. Source routing is a routing technique in which the sender of a packet determines the complete sequence of nodes through which to forward the packet; the sender explicitly lists this route in the packet's header, identifying each forwarding "hop" by the address of the next node to which to transmit the packet on its way to the destination host. The sender knows the complete hop-by-hop route to the destination. The protocol consists of two major phases: route discovery and route maintenance. Route discovery allows any host in the ad hoc network to efficient discover a route to any other host in the ad hoc network, whether directly reachable within wireless transmission range or reachable through one or more intermediate network hops through other hosts. Route maintenance is the mechanism by which a packet's sender detects if the network topology has changed such that it can no longer use its route to the destination because two nodes listed in the route have moved out of range of each other. When route maintenance indicates a source route is broken, the sender is notified with a route error packet. The sender can then use any other route to the destination already in its cache or can invoke route discovery again to find a new route.

Table 2. The average number of hops for a packet that successfully reached the destination node for various numbers of connections

Connections	802.11	M802.11	E802.11
5	2.212	2.248	2.082
10	2.541	2.499	2.340
15	2.643	2.580	2.407
20	2.731	2.637	2.449
25	2.480	2.455	2.335
30	2.347	2.274	2.299

Table 2 shows the average number of hops for a packet that successfully reached the destination node, at various numbers of connections. We can see that there are roughly equal numbers of hops for

802.11, M802.11 and E802.11 in all cases. In order to better understand the characteristics of E802.11 wireless networks in scenarios considered for this paper, we evaluated the performance of 802.11, M802.11 and E802.11 in ad hoc networks based on the following metrics:

-Packet delivery ratio: the ratio between the number of packets received by the CBR sinks at the final destination and the number of packets originated at the "Application layer" of CBR sources;

-End-to-end goodput: the actual bandwidth that is obtained by CBR connections;

-End-to-end delay per packet: the total delay experienced by a packet that successfully reached the destination node;

-Energy dissipation per packet: the average energy dissipation experienced by a packet that successfully reached the destination node.

6. Performance Evaluations

In this section, we evaluate how our proposed efficient backoff mechanism impacts the performance of the wireless ad hoc networks.

6.1. Packet delivery ratio

Fig. 1 shows the packet delivery ratio versus the number of connections 5, 10, 15, 20, 25 and 30 CBR connections for 802.11, M802.11 and E802.11. From Fig. 1, we see that the packet delivery ratio is about 1 when the traffic load is light (5 CBR connections). When the traffic load is moderate to high (10 to 30 CBR connections), the packet delivery ratio becomes lower. In the case that the packet delivery ratio is lower than 1, some packets are queued or discarded somewhere in the network. We further looked into the detailed operations and found that packets are lost at the intermediate (or relay) nodes but not at the sources. Higher loading at the radio/MAC layer increases the probability of frame collision and decreases the network performance. From Fig. 1, we know that the packet delivery ratio for E802.11 is much higher than that for 802.11 and M802.11.

In other words, more successful radio transmissions are spent on packets that do not reach their final destinations due to the increased traffic loading at the MAC layer. In addition, E802.11 takes the probability of collision for a transmitted frame as the metric of the contention window control scheme and this will decrease the congested nodes. When the probability of collision for a transmitted frame is included in contention window control scheme, more successful radio transmissions create more successful CBR packet delivery. The network wastes less network resource and this will improve the network performance. This shows that E802.11 achieves better network performance than do either 802.11 or M802.11.

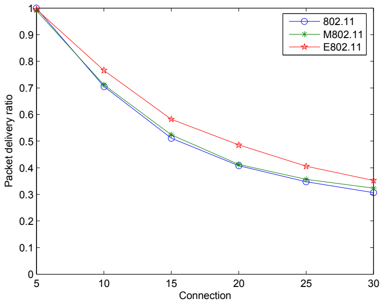

Figure 1. Packet delivery ratio versus the number of connections

6.2. End-to-end goodput

In Fig. 1, we note that at 5 CBR connections, the packet delivery ratio remains independent of the 802.11 and M802.11 or E802.11 because 5 CBR connections offer light load to the network and the network has enough capacity to handle them. However, the packet delivery ratio does not tell us the real data rate that the network delivered. Instead, the goodput is the appropriate metric for the carried data rate.

Fig. 2 shows the end-to-end goodput vs. the connections for 802.11, M802.11 and E802.11. And we know that the end-to-end goodput for E802.11 is much higher than that of 802.11 and M802.11. In Fig. 2, as the number of CBR connections increases, the end-to-end goodput also increases. When the number of connections is large, the end-to-end goodput increases. In addition, given a particular CBR connection number, the goodput for E802.11 is still higher than 802.11 and M802.11.

Take an example from Table 2: we know that the average number of hops for a packet that successfully reaches the destination node is about 2.407 at 15 connections for E802.11. From Fig. 2, we know that the end-to-end goodput is about 0.360 *Mbps* at 15 connections for E802.11. So, we know that the required per-hop throughput should be roughly 2.407 x 0.360 *Mbps* = 0.867 *Mbps* at 15 connections for E802.11. Fig. 2 shows the end-to-end goodput vs. the connections for 802.11, M802.11 and E802.11. And we know that the end-to-end goodput for E802.11 is much higher than that of 802.11 and M802.11. In Fig. 2, as the number of CBR connections increases, the end-to-end goodput also increases. When the number of connections is large, the end-to-end goodput increases. In addition, given a particular CBR connection number, the goodput for E802.11 is still higher than 802.11 and M802.11.

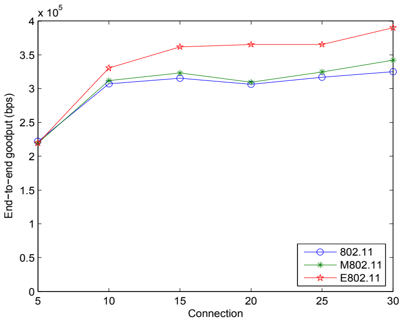

Figure 2. End-to-end goodput versus the number of connections

Fig. 3 shows the per-hop throughput vs. the number of connections for 802.11, M802.11 and E802.11. It demonstrates that the per-hop throughput for E802.11 is higher than that for 802.11 and M802.11, in particular at the higher connection numbers; when the connection number is between 15 and 30, the per-hop throughput ranges from 0.858 to 0.892 *Mbps* for E802.11 from 0.777 to 0.834 *Mbps* for M802.11, and from 0.762 to 0.836 *Mbps* for 802.11. When the traffic load is low, e.g., at 5 and 10 connections, the traffic does not fully utilize the network capacity; therefore, the goodput is lower than that when there are 10 to 30 connections for 802.11, M802.11 and E802.11.

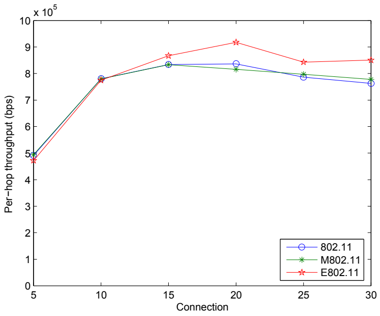

Figure 3. Per-hop throughput versus the number of connections

6.3. End-to-end delay

In [21], the authors show that the physical transmission delay and routing delay are relatively small and total packet delivery delay is dominated by the MAC delay. The per-hop MAC delay remains about the same regardless of the average number of neighbors. For a multihop network, more hops are required for each packet to reach the destination. Therefore the total delay due to MAC contention is higher for higher loading. For the routing delay, we observe that the per-hop routing delay is higher for larger average numbers of neighbors because the queuing delay is included in the routing delay for each node. For a network with a large average number of neighbors, packets are typically sent to the destination in one or two hops. Therefore there will be more packets queued at the source node or intermediate nodes, and hence longer queuing delay. For a network with a smaller average number of neighbors, queued packets are distributed over the nodes over a longer path; hence each node shares the queuing of the packets and means shorter queuing delay. When summing up all of the per-hop queuing delays, the end-to-end queuing delays for different average number of neighbors are about the same.

In this paper, each node has a nominal radius of 250 meters. Therefore, the end-to-end delay per packet or per hop will not be affected by the range of a transmission. The order of delay size is 802.11, M802.11 and E802.11 if we observe the contention window size of each scheme. But in [21], the authors show that the total packet delivery delay is dominated by the MAC delay. In E802.11, we consider the probability of collision for a transmitted frame into the backoff scheme. Therefore, from Tables 3, we see that E802.11 is slightly lower than 802.11 and M802.11 for end-to-end delay per packet in most situations.

Table 3. End-to-end delay per packet (sec) vs. the number of connections

Connections	802.11	M802.11	E802.11
5	0.013	0.102	0.050
10	1.173	1.173	0.951
15	2.284	2.320	2.035
20	3.549	3.220	2.910
25	3.953	3.751	3.911
30	4.289	4.126	4.269

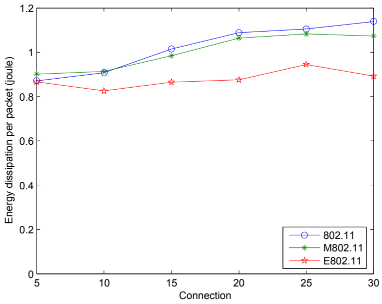

Figure 4. Energy dissipation per packet vs. the number of connections

6.4. Energy dissipation

Fig. 4 shows the energy dissipation per packet vs. the number of connections for 802.11, M802.11 and E802.11. And we know that the energy dissipation per packet for E802.11 is much lower than that for 802.11 and M802.11. In Fig. 8, as the number of CBR connections increases, the energy dissipation increases. When the number of connections is large, the energy dissipation increases. Nonetheless, given a particular number of CBR connections, the energy dissipation per packet for E802.11 is still lower than 802.11 and M802.11.

From Fig. 4, we can see that the energy dissipation per packet for E802.11 is much lower than that for 802.11 and M802.11. The reason is that we consider the node's probability of frame collision in the contention window control scheme; this will decrease the probability of collision in a two-hop contention area and save more energy consumption.

7. Conclusions

We have proposed an efficient backoff mechanism (E802.11) for ad hoc networks using the 802.11 DCF. We used the simulation experiments to evaluate the performance of E802.11 in comparison with the original 802.11 and M802.11. We find that E802.11 produces higher end-to-end goodput than 802.11 and M802.11. E802.11 also achieves better power saving by taking a node's probability of frame collision into consideration in the designing of the contention window control mechanism. In addition, given a particular CBR connection number, the energy dissipation per packet for E802.11 is still lower than that for 802.11 and M802.11. There are many other factors (e.g., routing, mobility) that affect the performance of a wireless ad hoc network, and they are topics for future research.

8. Acknowledgment

The authors would like to thank the reviewers for their helpful comments. Their remarks greatly improved the presentation of the paper. This work is supported by National Science Council under grant NSC 98-2221-E-343 -004.

9. References

[1] Ting-Chao Hou, Tzu-Jane Tsai, "An Access-Based Clustering Protocol for Multihop Wireless Ad Hoc Networks", IEEE Journal on Selected Areas in Communication, Vol. 19, No. 7, pp. 1201 ~ 1210, 2001.

[2] Karthigeyan I, Manoj BS, Murthy Siva Ram C, "A Distributed Laxity-based Priority Scheduling Scheme for Time-sensitive Traffic in Mobile Ad Hoc Networks", Ad Hoc Networks, Vol. 3, pp. 27 ~ 50, 2005.

[3] Shugong Xu, Tarek Saadawi, "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad Hoc Netwoks ? ", IEEE Communication Magazine, pp. 130 ~ 137, 2001.

[4] Marek Natkaniec and Andrzej R Pach, "An Analysis of the Backoff Mechanism used in IEEE 802.11 Networks", Proc. Fifth IEEE Symposium on Computers and Communications, pp. 444 ~ 449, 2000.

[5] Marek Natkaniec and Andrzej R Pach, "An Analysis of the Influence of the Threshold Parameter on IEEE 802.11 Network Performance", Wireless Communications and Networking Conference, Vol.2, pp. 819 ~ 823, 2000.

[6] Sharma S, Gopalan K, Zhu N, "Quality of Service Guarantee on 802.11 Networks", Hot Interconnects, Vol. 9, pp. 99 ~ 103, 2001.

[7] Dutkiewicz E, "Impact of Transmission Range on Throughput Performance in Mobile Ad Hoc Networks", IEEE International Conference on Communications, Vol. 9, pp. 2933 ~ 2937, 2001.

[8] Hadi Minooei, Hassan Nojumi, "Performance evaluation of a new backoff method for IEEE 802.11", Computer Communications, Vol. 30, pp. 3698 ~ 3704, 2001.

[9] Bianchi Giuseppe, "Performance analysis of the IEEE 802.11 Distributed Coordination Function", IEEE Journal on Selected Areas in Communications, Vol. 18, No. 3, pp. 535 ~ 547, March 2000.

[10] Juki Wirawan Tantra, Chuan Heng Foh, Adel Ben Mnaouer, "Throughput and Delay Analysis of the IEEE 802.11e EDCA Saturation", IEEE International Conference on Communications, Vol. 5, pp. 3450 ~ 3454, Mar. 2005.

[11] IEEE Std. 802.11. Wireless LAN Media Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.

[12] Yi-Cheng Chan, Ming-Chun Liao, "Collision-Aware Backoff Mechanisms for IEEE 802.11 WLANs", JCIT, Vol. 5, No. 2, pp. 88 ~ 100, 2010

[13] Dileep Kumar, Saleem Ahmed, Yeonseung Ryu, "Quality of Service (QoS) of Voice over MAC Protocol 802.11 using NS-2", JCIT, Vol. 3, No. 4, pp. 76 ~ 83, 2008

[14] Haider M. AlSabbagh, Ali Amin , "Kalman Filter Estimation of the Number of Competing Terminals in an IEEE 802.11 Network Utilizing Error Pron-Channel", IJACT, Vol. 2, No. 1, pp. 86 ~ 92, 2010

[15] Luis Muiioz, Marta Garcia, Johnny Choque, Ramon Aguero, "Optimizing Internet Flows over IEEE 802.11b Wireless Local Area Networks: A Performance-Enhancing Proxy Based on Forward Error Correction", IEEE Communications Magazine, Vol. 39, pp. 60 ~ 67, December 2001.

[16] Razafindralambo T, Valois F, "Performance Evaluation of Backoof Algorithms in 802.11 Ad Hoc Networks", International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems, Spain, pp. 82 ~ 89, 2006.

[17] Kevin Fall, Kannan Varadhan, eds., "Ns Notes and Documentation", VINT Project, University California, Berkely, CA, LBL, USC/ISI, and Xerox PARC, 1998.

[18] Bruce Tuch, "Development of WaveLAN, an ISM Band Wireless LAN", ATT Technical Journal, Vol. 72, No. 4, pp. 27 ~ 33, July/August 1993.

[19] David A Maltz, Josh Broch, Jorjeta Jetcheva, David B Johnson, "The Effect of On-Demand Behavior in Routing Protocols for Multihop Wireless Ad Hoc Networks", IEEE Journal on Selected Areas in Communications, Vol. 17, No. 8, pp. 1439 ~ 1453, August 1999.

[20] David B Johnson, David A Maltz, "Efficient Source Routing in Ad Hoc Wireless Networks", Mobile Computing, Kluwer Academic Publ., 1996.

[21] Ting-Chao Hou, Chien-Min Wu, Ming-Chan Chan, "Performance Evaluation of Wireless Multihop Ad Hoc Networks Using IEEE 802.11 DCF Protocol", IEICE Transactions on Communications, Vol. E86-B, No. 10, pp. 3004 ~ 3012, October 2003.